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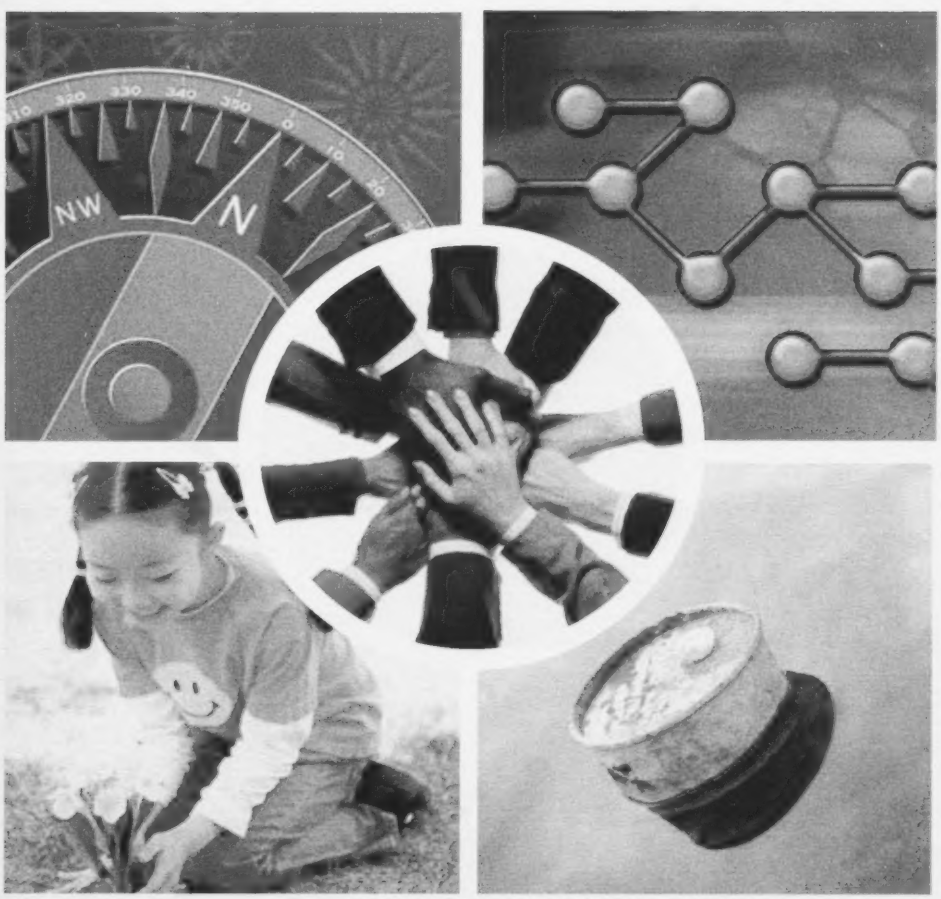
Supplemental Guidance on Human Health Risk Assessment of Indoor Settled Dust ($HHRA_{DUST}$)



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FEDERAL CONTAMINATED SITE RISK ASSESSMENT IN CANADA

SUPPLEMENTAL GUIDANCE ON HUMAN HEALTH RISK ASSESSMENT OF INDOOR SETTLED DUST ($HHRA_{DUST}$)

February 2018

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TABLE OF CONTENTS

PREFACE iv

ABBREVIATIONS AND ACRONYMS v

1.0 INTRODUCTION 1

1.1 Purpose 1

1.2 Background 2

1.3 Scope of this Document 3

1.4 Layout of Document 3

2.0 DEVELOPING A CONCEPTUAL MODEL FOR ASSESSMENT OF INDOOR DUST 4

2.1 When to Consider Assessment of Indoor Dust 4

2.2 Assessment of COPCs in Indoor Dust 5

3.0 SAMPLING OF INDOOR DUST 5

3.1 Characterization of Indoor Dust 6

3.1.1 Determination of Percentage of Dust From Soils 7

3.2 Indoor Dust Sampling Method 8

3.2.1 Wipe Sampling (Surface Area Measurement) 10

3.2.2 Vacuum Sampling (Bulk Dust Measurement) 10

3.2.3 Wipe Versus Vacuum Sampling 11

3.2.4 Recommendations for Dust Sampling 12

3.3 Laboratory Analysis 13

3.4 Quality Assurance and Quality Control 13

4.0 INCLUSION OF COPCS IN INDOOR DUST IN AN HHRA 14

4.1 Selecting COPCs in Dust 15

4.1.1 Screening Against DSC_{HH}—Surface Area and Bulk Dust 16

4.1.2 Screening Against Baseline Dust Concentrations 16

4.1.3 Selection of COPCs 19

4.2 Receptor Characterization 19

4.3 Exposure Characterization Assumptions 22

4.4 Concentrations of COPCs in Indoor Dust—Use of Appropriate Statistics 24
4.4.1 Use of Maximum Concentration Versus Mean Concentration 24
4.4.2 Incorporation of Data with Non-Detected Concentrations 24
4.4.3 Data Requirements 24
4.5 Toxicity Assessment 25
4.6 Bioavailability of COPCs in Indoor Dust 25
4.7 Risk Characterization 25
5.0 CONCLUSIONS 26
6.0 REFERENCES 27
APPENDIX I 34
APPENDIX II 39

LIST OF TABLES

TABLE 1: Examples of Published Sampling Protocols for Indoor Dust 9

TABLE 2: Possible Advantages and Disadvantages of Vacuum Versus Surface Wipe Sampling Methods* 12

TABLE 3: Examples of Published Canadian Baseline Dust Data 17

TABLE 4: Example Receptor Characteristic Parameters to Derive Dust Screening Concentrations* 20

TABLE 5: Example Exposure Parameters to Derive Dust Screening Concentrations* 22

TABLE 6: Site-Specific Input Parameters for HHRAs 24

PREFACE

The Federal Contaminated Sites Action Plan (FCSAP) is a program of the Government of Canada designed to ensure improved and continuing federal environmental stewardship as it relates to contaminated sites located on federally owned or operated properties or non-federal lands for which the federal government has accepted full responsibility. Guidance documents on human health risk assessment (HHRA) prepared by the Contaminated Sites Division of Health Canada, may be obtained by contacting the Contaminated Sites Division at: cs-sc@hc-sc.gc.ca.

This guidance document was prepared for the benefit of custodial departments who are assessing indoor settled dust as part of a risk assessment. As is common with any national guidance, this document may not satisfy all custodian site specific requirements. As the practice of HHRA advances and as the FCSAP proceeds, new and updated information on various aspects of HHRA will be published. Therefore, revisions to this document will likely be necessary from time to time to reflect new information. Health Canada should be consulted at the address below to confirm that the version of the document in your possession is the most recent edition and that the most recent assumptions, parameters, etc., are being used.

In addition, Health Canada requests that feedback on this document be directed to the Contaminated Sites Division, Safe Environments Directorate, Healthy Environments and Consumer Product Safety, Health Canada, e-mail: cs-sc@hc-sc.gc.ca.

See also: www.canada.ca/en/health-canada/services/environmental-workplace-health/contaminated-sites.html

Health Canada acknowledges the feedback and review comments received from a variety of government, academia and industry parties during the preparation of this guidance document. Health Canada also acknowledges the extensive work completed by Meridian Environmental Inc., Millenium and Wilson Scientific under contract to Health Canada.

ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrometry
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CCME	Canadian Council of Ministers of the Environment
CHDS	Canadian House Dust Study
COPC	Contaminant of potential concern
DQO	Data quality objective
DQRA	Detailed quantitative risk assessment
DSC	Dust screening concentration
DSC_{HH}	Human health-based dust screening concentration/s
FCSAP	Federal Contaminated Sites Action Plan
GC-MS	Gas chromatography-mass spectrometry
HC	Health Canada
HEPA	High efficiency particulate air
HHRA	Human health risk assessment
HQ	Hazard quotient
HVS3	High Volume Small Surface Sampler
ICP-MS	Inductively coupled plasma-mass spectrometry
ICP-OES	Inductively coupled plasma-optical emission spectrometry
IEUBK	Integrated Exposure Uptake Biokinetic model
ILCR	Incremental lifetime cancer risk
INAA	Instrumental neutron activation analysis
MAD	Median absolute deviation
PAH	Polycyclic aromatic hydrocarbons
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PQRA	Preliminary quantitative risk assessment
QA	Quality assurance
QC	Quality control
SF	Slope factor for carcinogenic potency
TDI	Tolerable daily intake
TRV	Toxicological reference value
US EPA	United States Environmental Protection Agency
US HUD	United States Department of Housing and Urban Development
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
WTCWG	World Trade Center Indoor Air Task Force Working Group

1.0 INTRODUCTION

Human health risk assessment (HHRA) is an approach used by health agencies and risk assessment professionals to estimate the potential effects of chemicals on human health. HHRAs form the basis of many of the guidelines and standards developed in Canada for establishing acceptable levels of chemicals in food, water, soil and air. Although Health Canada (HC) has used HHRA principles to develop various soil quality guidelines and risk-based decisions for many years, there are no standard assumptions and methods for assessment of indoor settled dust. This guidance document is intended to provide guidance on the key issues and methods used to assess potential health risks associated with chemicals from contaminated sites that may impact settled dust, in particular at federal contaminated sites in Canada.

Dust in the indoor environment is a complex matrix formed from a variety of anthropogenic, natural, indoor and outdoor sources, to which people are exposed as a whole. Assessment of human health risks associated with chemicals at contaminated sites may include evaluation of several types of environmental media such as soils, water, air, food and dust. Many of the chemicals present at contaminated sites are also found at non-contaminated sites, originating, for example, from background natural sources (such as naturally occurring minerals) or anthropogenic chemicals used in consumer products. Interpretation of levels of chemicals in dust may be difficult. Background/baseline dust concentrations from non-contaminated areas may provide a meaningful point of comparison to interpret what is typical and atypical for a given site and to assist in assessing the impacts of contaminated soils on indoor dust.

HHRA is a dynamic science, and therefore, acceptable practices change over time with new scientific developments. Discussion with HC staff is encouraged to ensure accordance with current methods and procedures. In addition, it is stressed that HHRA should be completed only by qualified and experienced risk assessment practitioners.

1.1 Purpose

The purpose of this guidance document is to recommend standard methods, exposure parameters and equations that can be used to quantitatively assess the potential exposures and risks to people from substances that may be elevated in indoor settled dust at federal contaminated sites due to outdoor sources. Further, information is provided for the risk assessor to derive human health-based dust screening concentrations (DSC_{HH}) and to assess exposure to contaminants of potential concern (COPCs) in indoor dust in quantitative human health risk assessments at federal contaminated sites.

The approach is specifically designed for the assessment of sites that are to remain the responsibility of federal agencies and of properties for which greater consistency in risk assessment methods and interpretation of results is required. For properties being divested to a private party or to provincial or municipal government agencies, HHRAs may have to be completed in accordance with provincial/territorial regulatory requirements. Local regulatory requirements may differ from the standardized methods described herein.

This guidance document was developed for use by federal custodial departments receiving funding under the FCSAP and to supplement Health Canada's Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals (DQRA guidance) (HC, 2010a) and is not intended for broader application outside of the FCSAP. HHRAs at contaminated sites consider the impact that historical activities may have had on various media, including soils, groundwater, surface water and air. This guidance document was prepared to address human health risks associated with chemicals present in indoor settled dust at federal contaminated sites when this medium is deemed to be of potential concern.

Although the guidance offered here is detailed in nature, it is not designed or intended as a substitute for the sound professional judgement of a qualified and experienced risk assessment practitioner. It is recognized that many HHRAs will present unique situations not specifically addressed here. Risk assessors are encouraged to ensure that their assessments address all relevant potential risks. The methods delineated should not be viewed as a "black box" of equations and assumptions that negate the need for sound professional judgement. However, where possible and appropriate, this guidance will help provide consistency in the approach used at federal sites. Where alternative or unique approaches have been used, these should be sufficiently documented and described to enable peer review and should be evaluated for their impact on risk estimates relative to the application of the standard methods prescribed.

1.2 Background

The United States Environmental Protection Agency (US EPA, 1997) defines house dust as "*a complex mixture of biologically-derived material (animal dander, fungal spores, etc.), particulate matter deposited from the indoor aerosol, and soil particles brought in by foot traffic.*" The German Verein Deutscher Ingenieure (VDI, 2001) Protocol 4300 states that "*there is currently no generally binding definition of the term settled house dust. To delimit the term from suspended particulate matter, it is intended to mean all types of particles which are encountered indoors in deposited form. The dust may be solids of the most varied inorganic or organic materials, which can be of natural or synthetic origin. The term includes not only fractions which originate indoors themselves, but also those which are introduced from the outside.*" These definitions of house dust, which highlight the deposited nature of this complex mixture of variable source, are adopted here. In this guidance, the term "house dust" is defined as above but can alternatively be referred to as "indoor settled dust," "settled dust," "indoor dust" and "dust." The term "soil" refers to outdoor soils.

Mounting evidence shows that exposure to environmental chemicals in indoor dust can be significant. An increasing number of studies have attempted to quantify chemical exposures from indoor dust, with results for certain chemicals such as lead and polybrominated diphenyl ethers (PBDEs) indicating that dust could represent a significant source of exposure for young children (Dixon *et al.*, 2009; Jones-Otazo *et al.*, 2005; Roberts *et al.*, 2009; US Department of Housing and Human Development [HUD], 2006). Correlations between blood lead levels (a measure of body burden) in children or adults and indoor dust concentrations or loadings (Dixon *et al.*, 2009; von Lindern *et al.*, 2003; Lanphear *et al.*, 1998) add weight to the importance of indoor dust as a potential source of chemical exposure. Dust may be a major source of exposure to pesticides, polycyclic aromatic hydrocarbons (PAHs), phthalates, arsenic, cadmium and chromium (Freeman *et al.*, 1997; Roberts *et al.*, 2009).

On average, Canadians spend approximately 90% of their time indoors (Matz *et al.*, 2014), which may result in greater exposure to indoor dust than to outdoor soil. The majority of time spent indoors is spent at home and other indoor locations including, but not limited to, work/school, grocery stores, shopping malls, and restaurants/bars (Matz *et al.*, 2015). People may be exposed to indoor dust via oral exposure through ingestion of settled dust from hand-to-mouth and object-to-mouth contact; via inhalation of re-suspended dust particles in indoor air; and also via dermal contact with settled dust. Elevated levels of chemicals in dust can present a potential exposure pathway at contaminated sites; this may require investigation at some sites, whereas at others the pathway may not be significant and/or operable.

In general, indoor dust consists of finer particles than does outdoor soil and contains higher organic carbon content and chemical concentrations. Finer particles adhere to the skin more effectively than coarse particles (Kissel *et al.*, 1996), resulting in higher exposures via hand-to-mouth and dermal contact. Further, characteristics of the indoor environment ensure that fewer degradation, aging and dispersive processes act on indoor dust as compared with outdoor soils, and certain indoor soft surfaces "trap" dust and result in continued exposure (Paustenbach *et al.*, 1997).

Exposures of young children to indoor settled dust are typically of greater concern given their vulnerabilities, and their exposure and behavioural characteristics. Young children frequently mouth hands, toys and other non-food items, and they crawl on floors in exploratory behaviours that may result in more skin contact, ingestion and inhalation of dust (US EPA, 2008a; Roberts *et al.*, 2009). Young children may also be more vulnerable to some chemicals in dust, given their immature systems (which may be less equipped to metabolize, detoxify and excrete chemicals), their rapid physical development and their vulnerability to developmental toxicants (US EPA, 2008a; Roberts *et al.*, 2009; Morgan *et al.*, 2005).

While the relationship between indoor air and settled dust is fluid and complex, the two are typically treated as discrete environmental media and assessed separately in HHRAs. Particles between about 1 nm and 100 µm may become suspended in air, depending on their physical properties and the forces and processes to which they are subjected (Morawska and Salthammer, 2004). Particles suspended in air may become deposited indoors as a result of particle diffusion (smaller particles) and gravitational sedimentation (larger particles), but particle deposition is highly variable, site-specific and difficult to quantify or predict (Morawska and Salthammer, 2004). Particles deposited as settled dust may also become re-suspended into indoor air, with larger particles being more readily re-entrained than smaller ones. Normal indoor activities, such as walking, moving around, playing or cleaning, have been shown to result in particle re-suspension (Morawska and Salthammer, 2004). Although some episodic inhalation of re-suspended dust (and associated chemicals) can be expected during such activities, these exposures are more appropriately assessed through an indoor air quality assessment, rather than through a settled dust assessment (with corresponding use of complex and uncertain modelling of deposition and re-suspension processes). Different air quality monitoring techniques are available that would enable assessment of temporal variations in air quality and exposure, and the appropriate type and duration of air sampling should be determined according to the needs of the air quality evaluation. Health Canada (2017) has a separate document which provides guidance on assessment of air quality. For the above reasons, this guidance deals with exposure via ingestion and dermal pathways, and excludes the inhalation pathway. It is recognized that in order to effectively assess the health risk of chemicals from contaminated sites for which indoor settled dust is an exposure source, all routes of exposure must be considered.

1.3 Scope of this Document

Residential and commercial environments were selected as the focus of this guidance document because indoor dust in these environments may be relevant to federal contaminated sites. Exposure assumptions as defined by the Canadian Council of Ministers of the Environment (CCME, 2006) and HC (2012a) for residential and commercial environments were assumed. Adult and toddler receptors are assumed to reside in residential environments, and adult employee and toddler receptors are assumed to be present in commercial environments. Other age groups may also be considered in risk assessments; however, the toddler receptor is typically the most sensitive, on the basis of ingestion rates and body weight. The "constrained use commercial" environment is assumed to be limited to adult employees. Specific exposure assumptions for these environments are available in HC (2012a). The HHRA should consider human uses of the site and apply the most appropriate land use designation.

Contaminated sites can include active working environments. Industrial or commercial environments where chemicals are used within the active work environment are typically considered under occupational worker health and safety legislation and/or regulations, and are not considered within this document.

1.4 Layout of Document

This report is organized as follows:

- Section 2 provides general guidance on when to consider assessment of exposure to chemicals in settled dust in an HHRA;
- Section 3 provides considerations for dust sampling;
- Section 4 provides a description of how to include dust as an exposure medium in an HHRA;
- Section 5 provides conclusions;
- Appendix I provides equations for calculating DSC_{HH}; and
- Appendix II provides equations for incorporating dust exposure assessment into HHRAs.

2.0 DEVELOPING A CONCEPTUAL MODEL FOR ASSESSMENT OF INDOOR DUST

A risk assessment of any contaminated site includes development of a conceptual site model at the problem formulation stage. This conceptual model will include identification of which exposure pathways, such as the indoor dust pathways, are operable at a particular site. A narrative should accompany the conceptual model to identify whether people may be exposed to chemicals in various media and the mechanisms of exposure.

Indoor dust may be considered a potential medium of interest at sites with contaminated surface soils. Concentrations of COPCs in indoor settled dust may become elevated through tracking of soil indoors, windblown dust and emissions during remediation or construction. Potential sources of indoor dust contamination should be identified in the conceptual model.

General information on problem formulation is not detailed further in this guidance document, and the reader is referred to HC's DQRA guidance (HC, 2010a) for further information, including the following:

- Screening and identification of COPCs;
- Identification and description of potential receptors;
- Identification of operable and inoperable exposure pathways;
- Description of the COPCs, critical receptor(s) and exposure pathways;
- Listing of all major assumptions used in the problem formulation; and
- Presentation of the problem formulation checklist (HC, 2012a).

2.1 When to Consider Assessment of Indoor Dust

The indoor dust ingestion and dermal exposure pathways are only considered operable if there is a source of contamination, a human receptor, a mechanism (pathway) for the contamination from the site to impact indoor dust, and subsequent exposure for people via ingestion and dermal exposure to dust. Airborne dust is assessed separately. Chemicals that are present in settled dust from sources other than the contaminated site would not be included in a contaminated site risk assessment, unless background exposure is assessed.

To assess when it is appropriate to pursue the evaluation of the indoor dust pathway, a series of questions need to be answered during the development of the conceptual model:

1. Does the contaminated site represent a significant source of contamination to indoor dust?
2. Is there a transport mechanism through which COPCs from the contaminated soil, outdoor dust and/or outdoor air at the site could impact indoor dust?
3. What are the exposure patterns and characteristics of the receptors with respect to indoor dust?
4. Do chemical concentrations in indoor dust exceed dust screening concentrations (DSCs)?

It is the responsibility of the federal custodial department with its qualified risk assessment practitioner to determine whether or not indoor dust should be sampled and included in an HHRA. Health Canada may be consulted during this process.

The assessment of indoor dust in an HHRA could be considered at federal contaminated sites under the following conditions:

- Soil track-in or airborne emissions of contaminated soils where substances exceed human health-based soil quality guidelines and which could impact settled dust;
- Comprehensive assessment of multiple environmental media is desired, and dust impacts are reasonably anticipated from contaminated sites; and,
- Local stakeholders have expressed concern over chemical concentrations inside their homes and buildings, and dust impacts can be reasonably anticipated to be from contaminated soils at or near the site.

2.2 Assessment of COPCs in Indoor Dust

COPCs are typically identified as chemicals that pose or have the potential to pose risks to human health. These chemicals are carried forward to the subsequent stages of the risk assessment (see HC [2010a] for more information). COPC concentrations in indoor dust may be measured directly or may be modelled from measured concentrations in soil.

At a contaminated site, the identification of COPCs is based on current and historical use of the property and the measurement of chemicals in environmental media, which will typically begin with an assessment of impacts to soils in environmental site investigations, as described in HC (2010a). For an assessment of indoor dust at a contaminated site, the COPCs associated with the site are identified from environmental site assessments and are discussed in the problem formulation stage of the HHRA.

Measured or modelled (predicted) concentrations of the COPCs in indoor dust can be compared with DSCs that can be calculated using the method presented in this report. If the measured or modelled concentration exceeds the DSC, the COPC would be retained for further evaluation within the HHRA.

3.0 SAMPLING OF INDOOR DUST

Before indoor dust is sampled, detection limits should be identified on a chemical-specific basis to ensure that they are adequate to support a risk assessment. The detection limits should be less than the calculated DSCs, and the risk assessor should identify the target level (e.g., the DSC or detection limit) prior to sampling and laboratory analysis.

This guidance document does not provide detailed information on modelling the impacts of soil on settled indoor dust, nor does it provide detailed information on sampling and analysis of chemicals in settled dust. The risk assessor should provide a summary of the scientifically defensible approach used to determine concentrations of chemicals in indoor dust.

The sampling plan should identify the areas of the building that will be sampled, in advance, along with supporting rationale. Areas of high exposure for toddlers or children, such as floors and window sills at hand level in frequently occupied rooms, are preferentially sampled in order to evaluate typical exposure and subsequent health risks.

Some sampling plans may also include undisturbed or infrequently cleaned areas, such as the tops of vents or ducts and behind or beneath large pieces of furniture, in order to obtain a measure of total levels of substances in settled dust in a building for determination of remediation requirements; however, these undisturbed areas are unlikely to be a significant source of exposure for people on a daily basis. If data from such areas are obtained, they should be used appropriately (i.e., given consideration of actual exposure) and discussed in the report.

Sampling considerations for indoor settled dust are discussed in the section below. As noted above, the information presented in this document is not prescriptive, and alternative methods may be used. The methods applied at a site should be summarized in the HHRA report, with potential uncertainties and limitations identified.

For the purpose of this guidance document, it is not possible to provide specific guidance on how to identify dust that is more likely to be impacted by contaminated soil; however, it is possible that dust in entryways would be impacted to a greater degree (e.g., as a result of contaminated soil tracked in on outdoor shoes), and these data may be used in interpretation of the COPC concentrations in other areas. Also to be considered in the collection of dust are the exposure of people in the buildings and the areas most likely to be used. Any areas expected to have higher COPC concentrations (such as those used for hobbies involving chemicals) should be identified. A clear rationale for sampling and analysis should be provided in the HHRA report as well as in the proposed sampling plan.

3.1 Characterization of Indoor Dust

The size of indoor settled dust particles, as well as their composition, is dependent on the source of the dust. The dust found in a building can originate from external sources such as contaminated soils, including tracked-in or re-suspended soil particles, but also from atmospheric deposition of particulates from industrial sources, forest fires, sea salt, heating plants and vehicular traffic (Davis and Gulson, 2005; Freeman *et al.*, 1997; Lioy *et al.* 2002; Morawska and Salthammer, 2004; Riley *et al.*, 2002). Additionally, indoor dust may originate from indoor sources, such as cigarette smoke, candles, cooking and heating residues, household appliances, maintenance products, textile fibres, human and animal skin particles and hair/fur, food crumbs, microorganisms, fungal spores, dust mite excreta, moulds, pollen, ash, soot, paper fibres and building materials (Afshari *et al.*, 2005; Agency for Toxic Substances and Disease Registry, 2002; Fan and Zhang, 2001; Klepeis *et al.*, 2003; Lazaridis *et al.*, 2008; Li *et al.*, 1993; Lioy *et al.*, 2002; Mølhave *et al.*, 2000; Morawska and Salthammer, 2004; Riley *et al.*, 2002; Rodes *et al.*, 1990; Zhang *et al.*, 2000). While airborne dust concentrations are often measured as $PM_{2.5}$ (particles with a diameter of 2.5 µm or less) or PM_{10} (particles with a diameter of 10 µm or less), the particle size of indoor dust can be highly variable.

Different sources of dust often have different particle size distributions, and different sizes and types of dust particles may also have different chemical characteristics, affecting the adsorption of chemicals to their surfaces. The surface area to mass ratio is greater in smaller particles, which may result in higher chemical concentrations in smaller particle size fractions (when expressed as mass of chemical per mass of dust). This is supported by a study of American residences (Lewis *et al.*, 1999), which found that concentrations of pesticides and PAH in indoor dust increased with decreasing particle size. The bioaccessibility of some metals has been shown to be influenced by particle size and also organic carbon content (Rasmussen *et al.*, 2008). In this study of vacuum dust from Ottawa, as particle size fraction decreased, bioaccessibility increased for nickel and copper but not for zinc.

Another difference with respect to indoor dust is that the organic carbon content is typically much higher than that in soil and often higher in the fine particle fraction than the coarse fraction. For example, Rasmussen (2004) found the organic carbon content to be approximately 4% in topsoil particles less than 53 µm, while the same size fraction in urban house dust from the same area had an organic carbon content of approximately 27.5%. This may contribute to higher concentrations of metals being associated with smaller particles as a result of binding with organic carbon (Rasmussen, 2004).

The intent of characterizing indoor settled dust at contaminated sites is to assess the contribution of the external contaminated media to the indoor COPC concentration in dust. It is important to note that for some substances (such as lead) that may be elevated in soils at a contaminated site, there may also be indoor sources not associated with the contaminated site, such as flaking and disintegration of interior paint. The COPCs in soils at a site (i.e., chemicals for which the maximum measured on-site concentration exceeds the applicable human health-based soil quality guideline) that are also present in indoor dust are included in a risk assessment as part of the overall assessment of exposure to the chemical at the site. In general, when collecting dust at contaminated sites for analysis, consideration needs to be given to characterizing the indoor dust most likely impacted by external media, rather than by indoor sources. This is important for risk management of contaminated sites and consideration of soil remediation options to reduce exposure.

This guidance document does not provide information regarding characterization of dust associated with indoor sources; however, the risk assessor will need to address this confounding factor as one of the uncertainties in the risk assessment.

3.1.1 Determination of Percentage of Dust From Soils

The infiltration of particulate matter from outdoors to indoors is affected by several factors, including outdoor particle concentrations, the building air exchange rate, the deposition rate of dust particles and the efficiency with which the particles can infiltrate the building. Abt *et al.* (2000) reported that 63% to 92% of indoor particles in the 0.02 µm to 0.03 µm range originated from outdoor sources, whereas in the 2 µm to 10 µm range only 20% to 43% of indoor particles were from outdoor sources. Data were included only for days when the air exchange rate was less than 1 exchange/hour to minimize the influence of air exchange; this rate is consistent with typical assumptions made for Canadian residences. Seasonal variation also affects infiltration of particles from outdoors (Long *et al.*, 2001; Morawska and He, 2004).

Some studies have shown indoor dust to have higher concentrations of metals than outdoor dust or soil (Rasmussen *et al.*, 2001; Oomen and Lijzen, 2004; Davis and Gulson, 2005). Rasmussen *et al.* (2001) reported that indoor dust differed significantly in multi-element composition from garden soil and street dust. In this study, the ratios of the geometric mean concentration of metals in indoor dust to their concentration in garden soils (i.e., the mean metal concentration observed in house dust [µg/g]/the mean metal concentration [µg/g] observed in garden soil) were calculated as 5.5, 16.4 and 3.4 for lead, cadmium and nickel respectively. The authors also concluded that dust generated from indoor sources may be significant for lead, cadmium, antimony and mercury. In a literature review of numerous studies and guidelines, Paustenbach *et al.* (1997) cited dust/soil concentration ratios for lead ranging from 0.3 to 9.2 in several North American and European studies, and pointed to evidence that indoor dust concentrations of cadmium, copper, zinc, pesticides and PAHs are often higher than in soil. While these observations may be indicative of additional indoor sources of these chemicals, the unique features of indoor dust as compared with soil (e.g., organic carbon content, degradation processes) may also explain higher chemical concentrations indoors (Paustenbach *et al.*, 1997).

Numerous studies have investigated the relative contribution of exterior soil to indoor dust. Oomen and Lijzen (2004) and Van Holderbeke *et al.* (2008) indicated that the contribution of exterior soil to interior house dust has been observed to range from 8% to >80%. The majority of the cited studies, however, report that 30% to 50% of house dust originates from exterior soil (Oomen and Lijzen, 2004). The US EPA (1998) Integrated Exposure Uptake Biokinetic (IEUBK) model for lead used a default value of 70% (i.e., 0.7 g soil/g dust). According to the US EPA (1998), the default value of 70% is based on an analysis of empirical data describing the relationship between soil and dust lead concentrations measured from a variety of residential communities. Oomen and Lijzen (2004) concluded that 30% to 70% of exterior soil present in house dust is likely a good approximation for evaluating exposure to indoor house dust. Cornelis and Swartjes (2007) recommended the use of 50% exterior soil in interior dust for residential scenarios with a garden or vegetable garden, an estimate also supported by analysis in Paustenbach *et al.* (1997). In homes without a garden, Cornelis and Swartjes (2007) suggest attributing 25% to exterior soil present in interior dust, although this estimate is associated with uncertainty. According to the literature, estimates of soil track-in contributions to dust vary considerably and are not recommended for predicting indoor exposures. For this reason, HC does not recommend a specific assumption for the percentage of dust that may originate from outdoor soils. Where it is important to know the site-specific ratio for risk management purposes, site-specific data should be collected.

Soil chemical concentrations and soil track-in estimates do not appear to be reliable general predictors of indoor dust concentrations, as such models have been shown to underestimate indoor exposures. Specifically, pilot studies for the Canadian House Dust Study (CHDS) demonstrated that predictive models (e.g., the IEUBK model mentioned earlier) do not hold where there is a lack of spatial correlation between elemental concentrations in indoor dust and outdoor soil, indicating a high degree of variability of indoor/outdoor concentration ratios (Rasmussen *et al.*, 2001; Rasmussen, 2004). In the city of Ottawa, such models underestimated the risk of indoor lead exposure by a factor of 8 and indoor nickel exposure by a factor of 9. When metal bioaccessibility was considered, the errors in the predictive models were even greater. Chemical concentrations in indoor dust are therefore not readily predicted using models based on either soil or outdoor particulate concentrations.

3.2 Indoor Dust Sampling Method

There are two primary methods of measuring indoor settled dust concentrations: surface wipe sampling (surface area measurement) and vacuum sampling (bulk dust measurement). Other methods, such as monitoring of heating, ventilation and air conditioning or other air ventilation systems (US EPA, 2005) or sampling attic dust (Lioy *et al.* 2002), can also be applied but are less commonly used and are not discussed further in this document.

Analytical considerations should be identified prior to sampling, on a chemical-specific basis, to ensure that the appropriate amount of dust sample is collected from each area of interest. Consultation with the analytical laboratory may be required before selecting the sampling technique and initiating sampling.

Wipe and vacuum sampling are often both used, sometimes in conjunction with air monitoring, in order to best utilize the strengths of each method and determine the distribution of chemicals. Field procedures generally involve isolating a known surface area to be sampled, either by taping off a square or placing down a template; obtaining the sample; and then transporting the sample to a laboratory for analysis.

Both wipe and vacuum sampling methods can provide surface loading levels (mass of chemical per unit area). Vacuum samples can also be analyzed to obtain the concentration of chemical by weight (e.g., µg/g), which allows for direct comparison with concentrations of COPCs in soil. Additionally, bulk samples from vacuum sampling can be used to assess particle size fractions. Some wipe sampling methodologies may also allow for determination of concentration by weight (Lioy *et al.*, 2002).

Several sampling protocols exist for procuring indoor settled dust samples by either wipe or vacuum methods. Health Canada does not specifically recommend any sampling protocols. The report should include the rationale for selecting a sampling protocol, identifying how the data will be used to assess exposure and how representative the samples are expected to be with regard to the risk assessment. Some protocols are listed in Table 1 as examples. Other sampling methods may be used and should be appropriately referenced.

Table 1: Examples of Published Sampling Protocols for Indoor Dust

Government Agency	Report Name	Report Date	Comments
American Society for Testing and Materials (ASTM)	ASTM E1728–10 Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination	2010	ASTM standard for dust wipe sampling for subsequent determination of lead.
ASTM	ASTM E1792–03 Standard Specification for Wipe Sampling Materials for Lead in Surface Dust	2011	ASTM specification for wipes that are used to collect settled dust on surfaces for the subsequent determination of lead.
ASTM	ASTM D5438–11 Standard Practice for Collection of Floor Dust for Chemical Analysis	2011	ASTM method for sampling dust from bare floors and carpet for chemical analyses.
California Department of Health Services	Exposure Investigation Protocol Dust Sampling in Building 240	April 2006 (revised)	Method for dust sampling (vacuum & wipes) at building with metals & pesticide/ herbicide impacts.
Community Environmental Health Resource Center	Lead Dust Background Materials	Undated	Instructions for sampling presented in checklist format; specific to dust related to lead paint.
US Department of Housing and Urban Development (US HUD)	Study of HUDs Risk Assessment Methodology in Three U.S. Communities	June 2006 (revised)	Evaluates sampling protocols and lead guidelines relative to their likelihood of predicting elevated blood lead.
US HUD	Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing	July 2012 (second edition)	Chapter 5 includes dust sampling methods; Appendix 13.1 contains detailed methods for wipe sampling (lead only).
US EPA Office of Pollution Prevention and Toxics	Residential Sampling for Lead: Protocols for Dust and Soil Sampling Final Report	March 1995	Dust sampling methods for wipes & vacuum, including details on laboratory preparation analysis (focus is on lead).
US EPA Office of Solid Waste and Emergency Response	Guidance for the Sampling and Analysis of Lead in Indoor Residential Dust for Use in the Integrated Exposure Uptake Biokinetic (IEUBK) Model	December 2008	Methods for collecting and analyzing residential dust lead data for use with the IEUBK model in Superfund risk assessments (lead only).
Verein Deutscher Ingenieure (VDI)	German Protocol VDI 4300, Part 8. Measurement of Indoor Air Pollution: Sampling of House Dust	June 2001 (withdrawn August 2012; revised December 2013 version [Part 11] only addresses airborne particulates)	Describes sampling conditions for house dust, including vacuum and wipe sampling for a variety of chemicals.

3.2.1 Wipe Sampling (Surface Area Measurement)

Wipe sampling is generally more cost-effective and simpler than vacuum sampling, and requires no special equipment. However, wipe samples can be obtained only from hard surfaces, and applying a consistent site sampling procedure among multiple individuals can be a challenge. Depending on the chemical being analyzed, researchers have used common cleaning wipes readily available at many stores; however, it is essential that the wipes used do not have elevated concentrations of the chemicals under consideration and that they do not contain substances that may interfere with the analysis.

A wipe sampling method was developed by the US Department of Housing and Urban Development (US HUD, 2012) for determination of lead. According to this method, wipes have to be of a single ply, cannot easily tear, must have low background levels of the target analytes, be digestible in a laboratory with a consistent recovery percentage and remain moist during sample collection. Other requirements may exist depending on the nature of the analyte and laboratory analysis to be performed.

Sampling is typically accomplished by wiping a known area in an "S" pattern using as much surface area of the wipe as possible while applying even pressure, then folding the wipe in half (sampled side in) and repeating the "S" motion perpendicular to the first pass (US HUD, 2012). Minor variations to the wiping procedure exist among protocols and are generally presented as a guideline to achieve consistent sampling throughout a site. Powder-free nitrile gloves are required to prevent contamination of the sampling area, and samples should be immediately stored in laboratory-approved containers.

3.2.2 Vacuum Sampling (Bulk Dust Measurement)

While generally more difficult and costly than wipe sampling, vacuum sampling can be applied to soft surfaces, such as upholstery, carpeting, rugs or drapes. Additionally, larger sample areas can be investigated as compared with those sampled with wipes, dust can be screened by particle size and, if the weight of dust collected is known, the chemical concentration in dust can be obtained in addition to the surface loading. The results of vacuum sampling are affected by several variables, including the type of carpet, age, condition, location in the residence and cleaning frequency (Lioy *et al.*, 2002).

Specialized units exist specifically for indoor dust sampling (e.g., CS3 Inc.'s HVS3 [High Volume Small Surface Samplers]), but some models of standard household vacuum cleaners can be adapted to obtain floor dust samples. Vacuum sampling requires an air pump apparatus with a removable filter, capable of maintaining a relatively constant flow rate. Sampling is performed by vacuuming in one direction across a known area at a constant rate. Vacuuming is repeated perpendicular to the previous pass and again in the opposite direction to the first pass. Filters, sampling canisters and/or bags are then removed from the unit and stored in Ziploc bags or containers provided by the analytical laboratory.

Vacuum sampling can be time consuming, as equipment should be regularly calibrated and cleaned (which may involve disassembling part of the vacuum) and the filter replaced after each sample. Overloading the vacuum can also be an issue, particularly for filter-based systems, as this can result in preferential sampling of smaller, less dense particles (US EPA, 1995) or may require multiple filters for a single sample area. Occasionally, there may be insufficient sample mass to meet analytical requirements, and sample collection from a larger area may be required. The actual area sampled should be calculated and provided in the report, in addition to the sample mass obtained. Where multiple samples are obtained in buildings, information related to each sampling area should be provided separately and shown on a figure.

Use of household vacuum cleaners can pose some problems, since each type has different design and particle collection/retention characteristics. Although the determination of particle size fraction distribution may be unreliable, household vacuums can provide information on the presence or absence of elements as well as the multi-element signature of the dust (Rasmussen *et al.*, 2001; Lioy *et al.*, 2002). Particle size fractionated mass distributions can be determined by use of a well-characterized standard vacuum (Lioy *et al.*, 2002). Several studies have relied on use of household vacuum cleaners with consistent results (Rasmussen *et al.*, 2001; Fan *et al.*, 2010).

At the current time, it would be inadvisable to collect household vacuum bags without knowledge of the areas sampled by the homeowner. Ideally, information should be gathered regarding the characteristics and activities in the home, such as home age, cleaning patterns and construction activities (Lioy *et al.*, 2002).

The specific type of sampling system used may depend to some extent on the desired particle size range, as filter-based systems may be more effective at sampling ultrafine particles, whereas systems with a sampling canister or bag can collect larger particles more readily. The flow rate of the vacuum, the collection efficiency, the precision and the size or portability of the unit may also be considerations (US EPA, 2008b).

Vacuum sampling methods used in the CHDS (e.g., Rasmussen *et al.*, 2011) were based on the German vacuum protocol (VDI, 2001). McDonald *et al.* (2010) provided information on wipe sampling methods used in the CHDS for lead and cadmium. McDonald *et al.* (2011) provided information related to wipe sampling for metals other than lead.

3.2.3 Wipe Versus Vacuum Sampling

Vacuum and surface wipe sampling can both be useful for evaluation of chemicals in indoor dust. One of the main advantages of surface wipe sampling is that chemical concentrations in units of $\mu g/m^2$ are better understood with respect to exposure potential. However, vacuum dust sampling can provide bulk concentrations as µg/g, which may be compared with concentrations in soil at a contaminated site. Additionally, larger dust samples can be obtained through vacuum sampling, which can allow for more extensive and sophisticated analysis techniques to be employed on the sample (such as speciation and synchrotron studies) (Rasmussen *et al.*, 2008, 2011; MacLean *et al.*, 2011).

In a workshop held by Health Canada in 2009, participants from academia, government and consulting companies provided feedback on the advantages and disadvantages of the two methods. Table 2 below provides a summary of some of the possible advantages and disadvantages of these sampling methods.

Table 2: Possible Advantages and Disadvantages of Vacuum Versus Surface Wipe Sampling Methods*

Sampling Method Considerations	Vacuum Sampling (Bulk Dust Measurement)	Surface Wipe Sampling (Surface Area Measurement)
International acceptance	European regulatory agencies are using this approach in addition to the USA (HVS3).	USA regulatory agencies are using this approach for lead (US EPA, US HUD, World Trade Center Indoor Air Task Force Working Group [WTCWG]).
Application for multiple chemicals	Published information on bulk dust concentrations is useful for multi-element studies (Rasmussen *et al.*, 2001).	Extensive wipe sampling results for lead are published in the literature; but not for other chemicals.
Cost and level of difficulty	More costly and time consuming to perform.	Easy and inexpensive to perform.
Particle size considerations	Able to include particle size considerations (Lioy *et al.*, 2002).	Typically cannot include particle size analysis.
Relationship to outdoor concentrations	Able to perform indoor-outdoor comparisons with soil, assuming that same particle size fractions selected.	Cannot perform indoor-outdoor comparisons because of difficulties collecting a surface wipe sample for soil or isolating specific particle size fractions.
Standardization of sampling protocol	Possible to apply standard sampling protocols consistently because minimal sample requirements can typically be met. Adds credibility and comparability to method.	Sometimes sampling protocol applied in a non-standard way as a result of lack of sample. (Expanding the area is recommended when a minimal sample is available.)
Spatial variability and sample size	Collection of composite bulk dust sample can avoid significant room-to-room variability, and since dust from multiple rooms can be combined, collection of an adequate sample size with reasonable detection limits is possible. Sampling can be conducted for individual rooms as well when information on spatial variability is needed.	Room-to-room variability can skew wipe sample results. However, information about individual rooms may be advantageous for examining spatial variability within residence.
Influence of housekeeping practices	Less likely to be influenced by recent housekeeping practices and thus may be more likely to provide information that would assist in source identification.	More likely to be influenced by recent housekeeping and may be more difficult to assist in source identification.

*Information based on opinions expressed at October 20th, 2009, workshop hosted by Health Canada's Contaminated Sites Division

3.2.4 Recommendations for Dust Sampling

As this document does not provide a recommended protocol for dust sampling, protocols developed by other agencies can be consulted when developing a site-specific protocol. Locations of samples should be identified prior to sampling and should be clearly stated in the HHRA report. The decision to sample high-use areas of the building or to conduct composite sampling should be identified in advance, and the supporting rationale and uncertainty discussion should be presented in the report.

Before conducting dust sampling, the project requirements and scope need to be evaluated, as well as the relative amount of hard versus soft surfaces present in the building(s) of interest, as these may affect the selection of sampling methods. In general, the following recommendations are made:

- Depending on the sample size requirements, it may be prudent to request that the building not be cleaned for one week before sampling to ensure that a sufficient sample size can be obtained.

- Vacuum sampling should be used for soft surfaces, using appropriate equipment.
- Either wipe sampling or vacuum sampling can be used for hard surfaces; if the concentration by weight is desired then vacuum sampling may be more appropriate.
- All sampling should be conducted in accordance with a comprehensive protocol and quality control/quality assurance program.
- Detection limits (and DSC) for each chemical should be identified in advance of sampling.
- A sampling plan should be submitted for review by the custodian prior to sampling.
- Custodian should confirm whether approvals are required in advance of sampling (e.g., if residences are sampled).

3.3 Laboratory Analysis

Specifications on laboratory analysis are not provided in this document. It is recommended that the analytical method be identified in advance of collection, as this may influence the amount of sample required. If one of the goals of the assessment is to identify how much contaminated soil is tracked in, then it may be prudent to identify whether the laboratory methods used would enable comparison of the concentrations in soil and indoor dust.

Various laboratory methodologies for the chemical analysis of vacuum dust are provided in published papers (e.g., Adgate *et al.*, 1995; Bai *et al.*, 2003; Fan *et al.*, 2010; Freeman *et al.*, 1997; Lewis *et al.*, 1999; Rasmussen *et al.*, 2008, 2011, 2013; Reynolds *et al.*, 1997; Rudel *et al.*, 2001), and methodologies for the analysis of surface wipes are also published (Adgate *et al.*, 1995; Bai *et al.*, 2003; Dufresne *et al.* 2011; Lioy *et al.*, 2000; McDonald *et al.*, 2010, 2011; Reynolds *et al.*, 1997).

The laboratory performing the chemical analyses should be certified by an accredited laboratory organization, such as the Canadian Association for Laboratory Accreditation or a similar organization like the Programme d'accréditation des laboratoires d'analyse of Quebec. If standardized methods have not been developed, then use of a research laboratory may be warranted, but in that case the analytical protocol and quality assurance procedures should be thoroughly documented and justified.

3.4 Quality Assurance and Quality Control

Quality control (QC) samples should be collected and analyzed to assess precision and/or bias of the sampling and analysis process. The collection and analysis of appropriate QC samples, as part of a quality assurance (QA) program, can help ensure that the quality of the data collected is known and that it meets a project's data quality objectives (DQOs). To establish the DQOs, the degree of certainty that is required should first be determined. QA consists of those activities that ensure that a defined standard of data quality with a stated level of confidence is met.

This document will not provide specific guidance on QA/QC requirements, and the information listed in this section is not a comprehensive guide. The report should identify the QA/QC procedures used as well as interpretation of the results (e.g., of duplicate or blank samples) and the associated uncertainty. A project's DQOs should be defined at the outset of the project to establish acceptable levels of data precision, bias, representativeness, completeness, comparability and detection limits. QA procedures, including the collection of field QC samples and their required frequencies, should be established in order to monitor whether the DQOs are being met. QC results should be reviewed and interpreted on an ongoing basis and the QA procedures modified as necessary. At project completion, an evaluation of the project data quality should be presented in a report.

The number of samples required for assessing loading or concentration in a location is dependent on the total area being evaluated and is often large for indoor settled dust analysis. Several duplicate samples are often required, as variability among samples can be high (US HUD, 2006) and neither the wipe nor vacuum samples collected on filters can be sub-sampled for different analyses (bulk vacuum samples can be sub-sampled). Other techniques, such as composite sampling, may or may not be available, depending on the chemical in question and the method of analysis. Additionally, many laboratory procedures for dust analysis require multiple additional blank and fortified samples in order to verify appropriate recovery levels from the sample matrix (US EPA, 1995).

The surface sampled may also affect the number of samples required. It has been shown that areas such as window sills can have higher variability than floors (US HUD, 2006), and a single samples may therefore not be representative of exposure. Compared with sampling of other media, such as soil or water, indoor settled dust sampling requires more consideration of the types of surface to be sampled in order to obtain meaningful results. Detailed documentation of the sample location as well as the surface type and use should be provided in the report.

Field quality control samples indicate the precision (random variation) and bias (systematic error) associated with field sampling. The types of sample that may be collected and analyzed to quantify the data precision or bias include, but are not limited to, the following:

- Field replicates—split of the same sample that measures sampling precision;
- Blank samples—indicate whether samples have been contaminated during the sampling, shipping or analysis stages. Typical blank samples include trip, field and equipment blanks. These may be wipes or vacuum cartridges that are not used for sampling but otherwise subjected to the same handling as the samples of interest.

Samples should be labelled with sample number and location for each sampling period. Samples prepared in the field should be stored at an appropriate temperature, as determined by the testing laboratory, and submitted to the testing laboratory within acceptable holding times (defined for each chemical with the testing laboratory during the scoping process). The wearing of gloves, proper decontamination and other QA/QC procedures should be respected and documented.

Laboratory QA/QC samples indicate the precision (random variation) and bias (systematic error) associated with laboratory analysis. The types of samples that may be analyzed to quantify the data precision and bias are as follows:

- Laboratory duplicates, which are splits of the same sample, taken in the laboratory and analyzed using the same procedures. The samples are used to ensure that method performance is within accepted limits;
- Fortified samples, which are samples to which a known quantity of a chemical has been added. This can include blanks or other samples being analyzed. The sample is run on the analytical instrument to assess instrument bias and to determine whether the sample matrix has an influence on the quality of the result; and,
- Reference standards (also known as "standard" or "certified" reference materials), which are samples prepared by a laboratory or an outside body and which contain specified concentrations of chemicals with a specified margin of error. The reference standards are used to calibrate analytical instruments.

4.0 INCLUSION OF COPCS IN INDOOR DUST IN AN HHRA

Inclusion of COPC in indoor dust as an exposure medium in an HHRA can be achieved by using a method consistent with that outlined in HC's DQRA guidance (HC, 2010a). The exposure assessment, which estimates the extent to which individuals are exposed to COPCs in dust, involves calculation of exposure to COPCs in the dust through both ingestion and dermal contact. The following sections provide some considerations relevant to indoor dust media at contaminated sites; they expand on the discussion of HHRA related to indoor dust found in the DQRA and preliminary quantitative risk assessment (PQRA) guidance documents (HC, 2012a; 2010a).

4.1 Selecting COPCs in Dust

Typically, at a contaminated site, concentrations of chemicals in soils are screened against guidelines or criteria developed for specific land uses by the CCME or provincial jurisdictions. Screening chemicals in dust to identify which substances are COPCs is more complicated than screening of chemicals in soil, as there are no environmental guidelines for the protection of human health for settled dust. As discussed above, COPCs from contaminated soils may impact indoor dust, and therefore the COPCs in soils would be used to target the chemicals at a contaminated site that may impact indoor dust and therefore need to be considered. This guidance has been prepared for application at historically contaminated sites and does not cover sites with industrial impacts on outdoor air and indoor dust. This guidance cannot provide prescriptive advice on when dust should be considered as an exposure medium, versus assessment of COPCs in soil without separate analysis of dust. This decision is the responsibility of the risk assessor, who would provide the rationale on a site-specific basis. Inclusion of dust as an exposure medium depends on the complexity of the risk assessment and would be considered in more complex assessments when human direct exposure to soil/dust is a critical pathway and the ingestion of dust and soil could be considered separately.

Further screening of soil COPCs is recommended whereby measured dust concentrations are compared with:

1. Human health-based dust screening concentrations (DSC_{HH}); and
2. Baseline dust concentrations (if available) that are typical of concentrations found in Canadian homes that are not impacted by contaminated sites.

This two-step approach is presented to meet the variable needs of contaminated site management. Sometimes the project requires concentrations based on human health effects to determine whether a dust concentration exceeds a level of potential human health significance. Alternatively, the project may require that dust concentrations be screened against available baseline concentrations to establish what is typical or atypical for a site. Project needs may dictate that both types of information are required for screening and interpretation. The report should describe the method used to screen COPCs, with references as appropriate.

DSC_{HH} can be developed on a site-specific basis prior to collection of samples and may be used for screening purposes provided that the values are interpreted appropriately by a trained risk assessment practitioner. The trained risk assessor should be aware of the assumptions and limitations of the DSC_{HH}, which can be calculated using the approach outlined in this report. If a COPC that is present at elevated concentrations in soils at the site is measured in dust at concentrations consistent with normal baseline concentrations for indoor settled dust in Canada, then that chemical would generally not be considered a COPC in dust. It is important that the statistical interpretation of such data be presented in the report and justified. Some information regarding assessment of baseline dust concentrations is presented in this report, and other information may be obtained from the published literature.

The statistics to be used to describe people's exposure to COPCs in indoor dust will depend on the quantity, quality and variability of available sampling data. It is important to apply a conservative estimate of exposure, based on the results of indoor dust sampling. Any decision to include dust in an HHRA needs to consider the concentrations of contaminants in dust to which people will be exposed (e.g., people are generally exposed to dust in the middle of a room, rather than dust in an unused attic space). The data used to estimate the exposure concentrations should be adequately described, and figures of sampling locations in the buildings should be included. Because of the intrusive nature of indoor sampling, it is often the case that fewer samples are available for settled dust measurements than for investigations of outdoor media. Consequently, upper-bound estimates of concentrations are often used in risk assessments, so that risks are not underestimated. For instance, typically one would use either the maximum or the 95th percentile of the data distribution, rather than mean concentrations.

The two-step approach for screening chemicals in dust is adapted from the CCME (2006) protocol, with further revisions based on work conducted by the WTCWG (2003). Deviations from the CCME (2006) approach include not assessing the background estimated daily intake to which a person would be exposed. Additionally, the concept of "geological background" dust concentrations was considered inapplicable and was replaced with a discussion of baseline dust concentrations.

The method for the calculation of the DSC_{HH} is provided in Appendix I.

4.1.1 Screening Against DSC_{HH}—Surface Area and Bulk Dust

This section presents human health effects-based dust concentrations as the **first step** for screening. This step should be considered if the project requires a determination of whether a dust concentration exceeds a level at which there is a potential for adverse human health effects.

Human health effects-based dust concentrations and baseline dust concentrations may be presented as both surface area (units of $\mu g/m^2$) and bulk (units of $\mu g/g$) measurements, because both are considered of relevance to human health.

Dust screening concentrations expressed in units of surface area will ensure that indoor environments that are particularly dusty will be given higher priority than environments that are not dusty. For example, two commercial buildings could have concentrations of a chemical in dust of 150 $\mu g/g$ and be treated similarly if only dust screening concentrations expressed as bulk dust concentrations are compared; however, if one of the buildings has a dust level of 1000 $\mu g/m^2$ and the second has a dust level of 100 $\mu g/m^2$, then the first building may be of higher priority from a health risk assessment perspective. Providing dust screening concentrations on a surface area basis therefore allows for the consideration of possibly greater exposures from dustier environments.

On the other hand, expression of dust screening concentrations as bulk dust concentrations can ensure that potential indoor sources are adequately considered without the confounding effects of recent cleaning. For example, depending upon cleaning habits, a residence with lead-based paint on window sills could have a surface area concentration that is similar to a residence without lead-based paint. However, if lead-based paint is flaking, measurement of dust as bulk dust concentrations may allow for identification of potential sources of exposure (i.e., high lead concentrations) even if the building is not particularly dusty. Thus, providing dust screening concentrations on a bulk dust concentration basis may allow for proper identification of potential sources regardless of cleaning habits.

One example of how both measurements may be important in different circumstances is a study conducted by Yiin *et al.* (2000), examining residential dust lead concentrations and their relationship to blood lead in preschool children. The findings suggest that dust measurements would be more relevant for health risk assessments when presented as dust concentrations in $\mu g/g$ for carpets but also as lead loadings in $\mu g/m^2$ on hard surfaces. In this study, blood lead concentrations correlated the highest with each of these measurements for the respective surface type.

For these reasons, dust screening concentrations may be developed as both surface area concentrations (i.e., $\mu g/m^2$) and bulk dust concentrations (i.e., $\mu g/g$).

Exposure calculations that may be used to derive DSC_{HH} are provided in Appendix I.

4.1.2 Screening Against Baseline Dust Concentrations

This section describes the use of available baseline dust concentrations as the **second step** for screening dust concentrations. This step should be considered if the project requires that dust concentrations be screened against available baseline concentrations to interpret what is typical or atypical for a region.

The concept of background, or baseline, concentrations of elements in soil versus dust differs significantly between the two media. This becomes apparent when comparing the background soil terms used in soil quality guidelines versus any measure of background dust for screening purposes.

Unlike soil, the concept of "natural" or "geological" background may not be applicable to indoor dust, since elements in dust stem from a variety of anthropogenic, natural, indoor and outdoor sources. Dust in the indoor environment is a complex matrix stemming from a variety of sources, to which inhabitants are exposed as a whole. Therefore, to isolate the portion of background dust that is considered to be natural/geological may not be particularly meaningful for dust exposure. Estimates of concentrations of chemicals in typical, urban background or "baseline" dust provide a more meaningful point of comparison for the interpretation of indoor dust samples at contaminated sites.

The use of an arithmetic mean baseline dust concentration is recommended for comparison when sufficient data are available, and when the data are normally distributed, since it is generally a conservative estimate of central tendency. Valid arguments may exist for selection of a different baseline dust concentration statistic, such as the median, 95% upper confidence limit of the mean, 95th percentile or maximum, and the report should provide a clear rationale for the statistic selected.

High-quality local or regional baseline dust data, where available, may be used for the interpretation of dust concentrations. Specific guidance is not provided for a dust sampling plan to collect regional data, as a statistical analysis would be required on a site-specific basis, as well as identification of areas not impacted by the site. In the absence of high-quality local or regional dust data, national baseline dust data published in the CHDS (HC, 2012b; see Table 3, below, for examples) may be useful for the interpretation of dust concentrations. Other sources can be considered when preferred sources are not available. Data quality can be evaluated by considering such factors as the chemicals tested, dust measurement made, particle size assessed, study design, sampling design, dataset quality, and scale and representativeness of the data.

Canadian studies on baseline concentrations of chemicals in dust exist and could be useful for interpreting dust sampling results from contaminated sites. The CHDS (HC, 2012b) measured baseline (typical urban background) dust concentrations from a combination of indoor, outdoor, anthropogenic and natural sources. The results of this urban, cross-country study are statistically significant and nationally representative.

Table 3 provides examples of some published and peer-reviewed sources of Canadian baseline dust data and summarizes key study considerations for use on a comparative basis. Most of the available data are from the CHDS. Additional local and regional Canadian baseline dust data may be available for comparison and should be considered on a project-specific basis.

Table 3: Examples of Published Canadian Baseline Dust Data

	Rasmussen *et al.* (2001)	Fan *et al.* (2010)	Rasmussen *et al.* (2011)	McDonald *et al.* (2011)	Rasmussen *et al.* (2013)
Chemicals tested	Ag, As, Be, Cd, Cr, Co, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sr, Tl, U, Zn (and others).	Parabens, triclosan, methyl triclosan	Pb	As, Cd, Cr, Cu, Ni, Pb, Sb	As, Cd, Cr, Cu, Ni, Pb, Zn
Study	Ottawa pilot study	Data subset from Canadian House Dust Study (CHDS)	Dataset from entire CHDS	Data subset from CHDS	Dataset from entire CHDS
Dust measurement	Bulk dust (µg/g)	Bulk dust (µg/g)	Bulk dust (µg/g)	Surface area dust (µg/m^2)	Bulk dust (µg/g), element loading (surface area dust; µg/m^2) and element daily loading rate (µg/m^2-d)
Particle size assessed	100–250 µm	<80 µm	<80 µm	Not applicable.	<80 µm (bulk dust); <300 µm (surface area dust & element daily loading rate)

	Rasmussen *et al.* (2001)	Fan *et al.* (2010)	Rasmussen *et al.* (2011)	McDonald *et al.* (2011)	Rasmussen *et al.* (2013)
Study design considerations	Urban. 50 private dwellings from Ottawa built between 1893 and 1987. Random sampling design.	Urban. 63 single-family dwellings from a Canadian city with population >100 000. Random sampling design.	Urban. 1025 single-family dwellings from 13 Canadian cities with population >100 000. Three-stage stratified random sampling design.	Urban. 222 single-family dwellings from 3 Canadian cities with population >100 000. Random sampling design.	Urban. 1025 single-family dwellings from 13 Canadian cities with population >100,000. Three-stage stratified random sampling design.
Sampling design	Composite fresh dust samples collected by participants from bare floors and carpets following a protocol designed to capture recent surface dusts and avoid longer-term sinks, and using participant vacuums.	Composite fresh dust samples collected from bare floors and carpets following the German vacuum protocol, Verein Deutscher Ingenieure (VDI), using Pullman-Holt High-Efficiency Particulate Air (HEPA) vacuum sampler. Household vacuum dust also obtained from vacuum systems used by participants.	Composite fresh dust samples collected from bare floors and carpets following the German VDI vacuum protocol, using Pullman-Holt HEPA vacuum sampler.	Wipe samples collected from non-carpeted floors only in various rooms (main entry area, kitchen, living and family rooms, adult and child bedrooms and children's primary play area) using Ghost Wipes following the American Society for Testing and Materials (ASTM) method E-1792.	Composite fresh dust samples collected from bare floors and carpets following the German VDI vacuum protocol, using Pullman-Holt HEPA vacuum sampler. Element loadings and loading rates were calculated from questionnaire data.
Dataset quality	48 samples. Not statistically significant.	63 samples. Not statistically significant.	1,025 samples. Statistically significant.	932 samples. Not statistically significant.	1025 samples. Statistically significant.
Scale of data	Local Ottawa, Ontario, study.	National but not nationally representative.	Nationally-representative.	National but not nationally representative.	Nationally representative.

	Rasmussen *et al.* (2001)	Fan *et al.* (2010)	Rasmussen *et al.* (2011)	McDonald *et al.* (2011)	Rasmussen *et al.* (2013)
Analytical methods used	Acid digestion and total element concentrations determined by cold-vapour AAS (Hg) and ICP-MS (all other elements).	Sonication extraction of samples and total chemical concentrations determined using GC-MS.	Bioaccessible Pb measured through dilute HCl extraction and modified European Toy Safety Protocol. Pb_T determined by 4-acid digestion and ICP-OES and ICP-MS.	Samples digested according to modified ASTM method E 1644, and concentrations determined by ICP-MS.	Total concentrations of Pb, Zn, Cu, Cd, Ni, As (62 samples) & Cr (some samples) determined by 4-acid digestion and ICP-OES or ICP-MS. For other samples, total concentrations of As & Cr determined by INAA.

Acronyms:

AAS: atomic absorption spectrometry

GC-MS: gas chromatography-mass spectrometry

HCl: hydrochloric acid

ICP-MS: inductively coupled plasma-mass spectrometry

ICP-OES: inductively coupled plasma-optical emission spectrometry

INAA: instrumental neutron activation analysis

Pb_T: total lead concentration

4.1.3 Selection of COPCs

COPCs in indoor dust should be determined by screening against DSC_{HH} and baseline concentrations. If a chemical at a contaminated site is considered a COPC in soil (by comparison against Canadian soil quality guidelines for the protection of human health (SQGs)), it should automatically be considered a COPC in dust, if dust is determined to be a media of interest. If no baseline concentrations are available, chemicals may be screened only against DSC_{HH}.

If the chemical concentrations are below baseline, the chemical would not be brought forward into the risk assessment for dust exposure alone. However, the data may be used as part of a multi-media exposure assessment. Dust would not be required to be remediated below baseline concentrations, because these are representative of the general public's exposure unaffected by contamination.

4.2 Receptor Characterization

Receptor characteristics are provided in the Health Canada PQRA Part 1 document (HC, 2012a) for risk assessments of contaminated sites on federal lands. The input parameters for receptor characteristics used in the assessment should be documented in a table in the report to ensure that the assessment is transparent and the calculations can be confirmed by a technical peer reviewer. For site-specific HHRAs, any site-specific behaviour should be addressed in the HHRA report, with justification provided.

Receptor characteristics provided as an example for the purpose of derivation of the DSCs are summarized in Table 4; however other values may be used based on site-specific exposure factors. Rationale for all receptor characteristics should be documented in the risk assessment. Upper-bound estimates of dust ingestion may be used in risk assessments, so that risks are not underestimated, which may include use of the 95th percentile of the data distribution, rather than mean concentrations.

The PQRA Part 1 document (HC, 2012a) does not provide a value for ingestion of indoor dust, and this parameter has not been extensively quantified in the published literature. For the purpose of derivation of DSCs, this parameter is required. Exposure to dust via object-to-mouth behaviours cannot be quantified by mass-balance soil ingestion studies since its relative contribution to excreted trace elements cannot be distinguished from that of soil (Calabrese and Stanek, 1992a, 1992b; Stanek and Calabrese, 1992; Stanek *et al.*, 2012). In addition, mass-balance studies of soil ingestion have been shown to have highly variable results and are often fraught with uncertainties (Wilson *et al.*, 2013; Stanek *et al.*, 2012). Two potential sources of bias in mass-balance analysis are the lack of identification of non-soil sources that contribute to exposure (toothpaste, medication, food, paint, paper, crayons, etc.) as well as actual bioavailability and body retention of the elements used (Stanek *et al.*, 2012).

Ingestion of settled indoor dust has been quantified in few studies in the published literature. Ozkaynak *et al.* (2011) modelled soil and dust ingestion rates using a mechanistic method based on the US EPA's Stochastic Human Exposure and Dose Simulation model. For children aged 3 to 6 years, Ozkaynak *et al.* (2011) predicted mean dust ingestion rates of 20 mg/day via hand-to-mouth behaviour and 7 mg/day of dust via object to mouth, with a mean soil ingestion rate of 41 mg/day. They estimated mean total soil and dust ingestion rates for this age group as approximately 68 mg/day.

Using a different approach to estimate dust ingestion rates, Wilson *et al.* (2013) conducted a probabilistic assessment based on a literature review. The authors estimated mean indoor dust ingestion rates ranging from 2 mg/d for teenagers to 41 mg/d for toddlers. This compared with a range of mean soil ingestion rates from 1 mg/d for seniors to 20 and 23 mg/d for toddlers and children respectively in the same study. Combined soil and dust ingestion rates were reported to range from 4 mg/d for seniors to 61 mg/d for toddlers. These combined soil and dust ingestion rates are lower than soil ingestion rates adopted by most agencies. However, the combined soil and dust ingestion rate for toddlers was similar to that estimated by Ozkaynak *et al.* (2011), and the toddler and child soil ingestion rates were comparable to the Stanek *et al.* (2012) mean estimate of 26 mg/d. Wilson *et al.* (2013) reported that these ingestion rates are mechanistic, can be adjusted on a site-specific basis, can be modified into an hourly rate and are presented as a more realistic alternative to traditional mass-balance approaches. These values have been provided as an example (Table 4); however, other values cited from scientific literature may be used. Additional details, including values recommended for probabilistic assessment, are available in Wilson *et al.* (2013).

Receptor characteristics, such as body weight and exposed dermal surface area, which are typically used in risk assessment of contaminated sites, are provided as an example in Table 4 below. Other parameters were identified from the published literature or calculated in the equations presented in Appendix I. Alternative values may be used in an HHRA with supporting rationale, ensuring that the risk assessment provides a conservative estimate of risk. Receptor characteristics identified in the risk assessment should be summarized, with a rationale for the selection.

Table 4: Example Receptor Characteristic Parameters to Derive Dust Screening Concentrations*

Generic Input Parameter	Value Selected	Reference
Body weight (BW)	Infant: 8.2 kg Toddler: 16.5 kg Child: 32.9 kg Teen: 59.7 kg Adult: 70.7 kg	Health Canada (2012a)
Dust ingestion rate (DIG)—residential	Infant: 0.038 g/day Toddler: 0.041 g/day Child: 0.031 g/day Teen: 0.0022 g/day Adult: 0.0025 g/day	Calculated from Eq. 7 (Appendix I)†

Generic Input Parameter	Value Selected	Reference
Dust ingestion rate (DIG)—commercial	Infant: 0.028 g/day Toddler: 0.027 g/day Child: 0.021 g/day Teen: 0.0014 g/day Adult: 0.0014 g/day	Calculated from Eq. 7 (Appendix I)†
Surface area of fingers inserted into mouth ($SA_{fingers}$)	Infant: 0.0013 m^2 Toddler: 0.0015 m^2 Child: 0.0021 m^2 Teen: 0.0020 m^2 Adult: 0.0022 m^2	Calculated from Eq. 2 (Appendix I)
Surface area of hands exposed to dust (both hands; SA_{hands})	Infant: 0.032 m^2 Toddler: 0.043 m^2 Child: 0.059 m^2 Teen: 0.080 m^2 Adult: 0.089 m^2	Health Canada (2012a)
Surface area of other body parts exposed to dust (SA_{other})	Infant: 0.146 m^2 Toddler: 0.258 m^2 Child: 0.455 m^2 Teen: 0.720 m^2 Adult: 0.822 m^2	Health Canada (2012a)
Skin adherence factor for dust on hands (SAF_{hands})	2 g/m^2-day	US EPA (2008a)
Skin adherence factor for dust on other body parts (SAF_{other})	0.3 g/m^2-day	US EPA (2008a)
Saliva extraction factor (SE)	0.5	WTCWG (2003) and Camann *et al.* (2000)
Sleep time (ST), residential only	Infant: 13 h/day Toddler: 10.5 h/day Child: 9.9 h/day Teen: 9.1 h/day Adult: 8.4 h/day	Health Canada (1995)

* Note that other values may be used with a detailed rationale (with citations)

† Rates are consistent with those from Wilson *et al.* (2013)

4.3 Exposure Characterization Assumptions

Most assumptions concerning exposure frequency and duration are based on best professional judgement, as there is a paucity of information in the published literature regarding typical exposure parameters. Where available, these values have been cited. For purposes of an HHRA for a federal contaminated site, the frequency and duration of site exposure should be based on the guidance presented in Table 5 unless, in the opinion of the risk assessor, alternative assumptions are more defensible. Justification for alternative assumptions should be provided and fully referenced. The reader is referred to the DQRA guidance (HC, 2010a) for a discussion of the implications of exposure amortization.

The recommended approach for estimation of exposure to chemicals in dust involves the estimation of exposure (in units of µg/kg-d) from the oral and dermal routes. These exposures are then summed to provide an estimate of the total exposure that could arise from indoor dust.

Dust exposures can be estimated assuming equal exposure to hard and soft surfaces or can be modified for buildings in which there is expected to be more or less exposure to hard or soft surfaces. The fraction of indoor time spent in contact with hard versus soft surfaces can be estimated to be 50/50, notably on the basis of results from a method development and evaluation study conducted under the national CHDS (McDonald *et al.*, 2011), which showed that, on average, 56% of homes surveyed had carpeted floors and 44% were not carpeted. Additionally, it can be assumed that people contact settled dust on surfaces that are soft (e.g., couches, beds) and hard (e.g., tables) on what could be an equivalent basis. "Hard surfaces" are defined as those composed of non-porous materials, such as hardwood, linoleum, tile, laminate, etc., and primarily refer to floors but do not exclude other hard dust-bearing surfaces such as countertops, tables, hard toys, and window sills. "Soft surfaces" are defined primarily as floors covered with carpets and rugs but not excluding other soft dust-bearing surfaces such as sofas, pillows and beds.

Several simplifying assumptions are made to allow for estimates of exposure, including the assumption that dust concentrations remain constant and that dust is transferred to hands with every contact event.

These exposures relate solely to contact with settled dust; airborne dust is evaluated separately through inhalation exposure assessments.

Table 5: Example Exposure Parameters to Derive Dust Screening Concentrations*

Generic Input Parameter	Value Selected	Reference
Dust surface loading on horizontal hard surfaces (DSL_{hard})	0.052 mg/cm^2	Arithmetic mean calculated from Johnson *et al.* (2009)
Dust surface loading on horizontal soft surfaces (DSL_{soft})	0.139 mg/cm^2	Arithmetic mean calculated from Roberts *et al.* (1999) and Laxen *et al.* (1988) datasets
Exposure frequency (EF)	Residential: 1 (7 d/wk, 52 wk/yr) Commercial: 0.71 (5 d/wk, 52 wk/yr)	Health Canada (2012a)
Exposure factor for transfer to body (EFB)	Residential: 1.8 hr/day (toddler) Commercial: 1.2 hr/day (toddler/adult)	Calculated from Eq. 4 (Appendix I)
Exposure factor for transfer to fingertips (EFF)	Residential: 5.17 hr/day (toddler) Commercial: 3.36 hr/day (toddler) 1.9 hr/day (adult)	Calculated from Eq. 3 (Appendix I)
Exposure time for contact with horizontal hard surfaces (ET_{hard})	Residential: 6.1 hr/day (toddler) Commercial: 4.0 hr/day (toddler/adult)	Calculated from Eq. 8 (Appendix I)

Generic Input Parameter	Value Selected	Reference
Exposure time for contact with horizontal soft surfaces (ET_{soft})	Residential: 6.1 hr/day (toddler) Commercial: 4.0 hr/day (toddler/adult)	Calculated from Eq. 9 (Appendix I)
Frequency of hand-to-mouth events (FQ)	Infant: 28 hr^{-1} Toddler: 16 hr^{-1} Child: 9.1 hr^{-1} Teen: 1.0 hr^{-1} Adult: 1.0 hr^{-1}	Geometric mean calculated from Xue *et al.* (2007)
Fractional surface area of fingers for mouthing activity ($FSA_{fingers}$)	Infant: 0.08 Toddler: 0.07 Child: 0.07 Teen: 0.05 Adult: 0.05	Median values from AuYeung *et al.* (2008)
Fraction of dust transferred from hard surfaces to body ($FTSS_{HSB}$)	0.25	WTCWG (2003)
Fraction of dust transferred from hard surfaces to hands ($FTSS_{HSH}$)	Infant: N/A Toddler: 0.7 Child: 0.7 Teen: 0.4 Adult: 0.4	Estimated from Rodes *et al.* (2001) based on dermal transfer factors
Fraction of dust transferred from soft surfaces to body ($FTSS_{SSB}$)	0.05	WTCWG (2003)
Fraction of dust transferred from soft surfaces to hands ($FTSS_{SSH}$)	Infant: 0.14 Toddler: 0.14 Child: 0.14 Teen: 0.08 Adult: 0.08	Estimated from Rodes *et al.* (2001) based on dermal transfer factors
Hours spent in environment each day (HPD)†	Residential: 24 hr/day Commercial: 8 hr/day	Health Canada (2012a)
Transfer coefficient (TC)‡	0.12 m^2/hr	WTCWG (2003)
Time spent outdoors (TO), assumed for residential only	Infant: N/A Toddler: 1.2 h/day Child: 2.2 h/day Teen: 1.4 h/day Adult: 1.4 h/day	Toddler and child based on US EPA (2008a) and supported by Leech *et al.* (1997, 2002); teen and adult from Richardson (1997)

* Use of these values is outlined in Appendix I.

† Note that some values may be altered on a site-specific basis, with rationale.

‡ The transfer coefficient represents the rate of skin contact with the surface.

4.4 Concentrations of COPCs in Indoor Dust—Use of Appropriate Statistics

4.4.1 Use of Maximum Concentration Versus Mean Concentration

Different statistics of the collected dust sampling data can be used to represent the concentration of a chemical in dust from which exposure is estimated. If limited data are available, the maximum measured concentration is recommended for use in exposure calculations. If the sample size is deemed sufficient and the collected samples are considered representative of the dust concentrations affected by the site, it may be possible to use a statistic representing the central tendency of the data (e.g., mean or median) for each building to provide a more realistic estimate of the typical or average concentration for exposure and risk calculation. Conservative estimates of the average exposure (such as the 95% upper confidence limit of the mean or median + 2*MAD [median absolute deviation]) are commonly used to maintain conservatism in the risk assessment where data are limited. The specific approach used will depend on the quantity and quality of the data and the purpose of the risk assessment, as well as considerations such as exposure duration, and should be determined on a case-by-case basis with appropriate justification. Often a tiered approach is applied in which maximum concentrations are used for the initial screening, and more realistic exposure estimates used if initial estimates exceed the DSC_{HH} or baseline.

Use of the geometric mean is not recommended. The geometric mean is a statistical representation of the central tendency of data that are log-normally distributed. However, this statistic is not necessarily representative of the average concentrations to which people will be exposed. The arithmetic mean (or upper confidence limit of the mean) is generally a more appropriate representation of the average or typical concentration to which a person will be exposed for normally distributed concentration data and a conservative estimate for other distributions (US EPA, 2002). The median may be a suitable measure of central value for other distributions (Reimann and Filzmoser, 2000; Reimann *et al.*, 2008).

4.4.2 Incorporation of Data with Non-Detected Concentrations

In some cases, measured dust concentrations may be reported as less than detection limit. Analytical data sets frequently include both reported concentrations (detects) and reported inability to detect the chemical (non-detects). Consequently, the low end of the distribution of concentrations is (left) censored. Non-detectable concentrations do not necessarily indicate that a chemical is absent, but rather, they indicate that the chemical may be absent or it may merely be present at concentrations below the method detection limit or quantification limit. If a chemical is detected in some samples from a site, it is possible that it is also present at low concentrations in samples reported as non-detects.

When a dataset includes non-detect values, methods to calculate exposure concentration point estimates for reported non-detect concentrations can be used, such as those described in the 'Soil Characterization Guidance' section of the *CCME (2016) Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment* (Volume 1). Regardless of the approach used to address non-detect values, appropriate justification and full references should be provided.

4.4.3 Data Requirements

The data should be provided in the risk assessment report, preferably including tabulated data for individual samples, as well as tables with statistical summaries of the data (max, mean, min, number of samples). Table 6 identifies site-specific parameters that are required for input in the equations in Appendix I.

Table 6: Site-Specific Input Parameters for HHRAs

Generic Input Parameter	Value Selected
Bulk dust concentration on horizontal surfaces (BDC)	Measured, site-specific value (µg/g)
Dust concentration from hard surfaces on an area-weighted basis (DCA_{hard})	Measured, site-specific value (µg/m^2)
Dust concentration from soft surfaces on an area-weighted basis (DCA_{soft})	Measured, site-specific value (µg/m^2)

Note: HHRA may use either approach (bulk or area-weighted) or both approaches

4.5 Toxicity Assessment

The HHRA includes a toxicity assessment, as described in the PQRA and DQRA guidance documents (HC, 2012a; 2010a). Toxicological reference values (TRVs) may be obtained from HC's Part II: Health Canada's Toxicological Reference Values and Chemical-Specific Parameters (2010b). Alternately, if values for specific COPCs are not available in HC (2010b), values from other regulatory agencies may be used, as specified in the PQRA and DQRA guidance documents. For further information please refer to HC (2012a; 2010a,b).

4.6 Bioavailability of COPCs in Indoor Dust

The DQRA guidance (HC, 2010a) provides a section on considerations related to the bioavailability of COPCs in soil as compared with the bioavailability in the study used to derive the TRV. This comparison may be done on a site-specific basis, as bioavailability is strongly influenced by the matrix in which the chemical is found. On the basis of available data, it is expected that the oral bioavailability of chemicals from dust would be similar to or higher than the bioavailability from soil, particularly when the dust originates from contaminated soil (Freeman *et al.*, 1995; Oliver *et al.*, 1999; Yu *et al.*, 2006; Ruby *et al.*, 1996, 1999; Rasmussen, 2004; Rasmussen *et al.*, 2008). Therefore, it is recommended that dust exposure estimates assume that the bioavailability of the chemical in the exposure medium is similar to that in the study used to derive the TRV unless site specific data are available. Specifically, a relative oral bioavailability factor of 1 can be assumed for most chemicals (i.e., the bioavailability from dust is assumed to be the same as the bioavailability from the exposure medium in the critical toxicity study), unless chemical-specific information is available.

Dust exposure estimates could theoretically be adjusted on a chemical-specific basis, with sufficient supporting rationale. Use of *in vitro* methods demonstrating adequate validation with *in vivo* data from a variety of sources would be preferred, and use of additional toxicodynamic/toxicokinetic information could be considered for chemicals for which the TRV is provided as a biomarker limit or absorbed/internal dose.

Dermal bioavailability from soil can be assumed to be representative of dermal bioavailability from dust. Although dermal relative absorption factors are specific to soil, they can be adopted for dust since there is a lack of any medium-specific information and because dermal absorption of chemicals from the two media is not expected to differ markedly.

4.7 Risk Characterization

Risk characterization is the HHRA phase in which the exposure and toxicity data are compared, as discussed in the PQRA and DQRA guidance documents (HC, 2012a; 2010a). DSCs are established using a back-calculation of the equations used to generate risk estimates.

To calculate DSCs, it is recommended that the guidance for soil quality guideline development (CCME, 2006) be followed, in which effects-based dust concentrations are based on 20% of the TRV for non-carcinogens, which is reflected as a target hazard quotient (target HQ) of 0.2, or, for carcinogens, on a target incremental lifetime cancer risk of 1×10^{-5} (1 in 100,000).

The CCME (2006) protocol for derivation of soil quality guidelines does not identify indoor dust as a separate medium. It identifies soil, air, drinking water, food and consumer products as media to which people may be exposed, allocating an equal portion of the TRV to each medium (e.g., 20% to each medium). For soil and dust, the soil ingestion rate used in the CCME (2006) protocol does not differentiate between exposure to soil and exposure to dust. When soil is considered at a contaminated site, there is a possibility that dust may also be impacted, and thus should also be considered. If dust has not been collected and analyzed at the site, soil and dust can be treated as the same exposure medium (by assuming soil concentrations are a surrogate for dust concentrations) and either the CCME (2006) soil ingestion rate or a combination of soil+dust ingestion rates (e.g Wilson *et al.* 2013) can be used in the risk assessment. If dust has been collected and analyzed at the site, it can be treated as a separate medium, and the dust ingestion rates published by Wilson *et al.* (2013) may be used in addition to the soil ingestion rates that were calculated specific to the 'soil ingestion pathway only' by Wilson *et al.* (2013)—when the values in that publication are suitable for the land use. Although CCME 2006 soil ingestion rates do not differentiate between soil and dust, methodology such as the one used in Wilson provides the ability to separate soil and dust ingestion rates.

Exposures to soil and dust (or sediment) are not expected to occur concurrently, and thus separate allocations to these media are not proposed. Assigning 20% of the TRV to set screening concentrations with regard to potential human health significance of any particular exposure medium is consistent with HC screening-level guidance (e.g., HC, 2012a). Therefore, an allocation of 20% for dust is recommended.

In a DQRA in which dust is one of the media assessed and exposure from all media plus background is incorporated, a target HQ of 1 may be appropriate. For further information please refer to HC (2010a).

5.0 CONCLUSIONS

The information provided in this supplemental guidance document is recommended for use in conjunction with other HC guidance on assessment of risk from contaminated sites, specifically the DQRA guidance (HC 2010a). Inclusion of dust as a separate exposure medium is anticipated in more complex risk assessments at sites where direct exposure to soil and dust are important exposure pathways and when a decreased amount of uncertainty is required for the purpose of risk management or evaluation of mitigation measures. HC, Contaminated Sites Division, may be contacted with questions on the assessment of indoor dust in a contaminated sites risk assessment. The guidance provided in this document is not intended to be used for any purpose other than for risk assessment of federal contaminated sites where indoor dust may be a significant exposure pathway.

The HHRA report should provide a section on calculation of DSCs for screening COPCs as well as assessment of the COPCs carried forward into the risk assessment. Equations provided in Appendix I may be used to derive DSCs. Those provided in Appendix II may be useful in calculating exposures and risks in an HHRA. These exposures and risks can then be summed with those from other exposure pathways to COPCs at the site (e.g., from other contaminated media). The guidance provided in the DQRA document (HC, 2010a) is also recommended for use in HHRAs which incorporate the dust exposure pathway.

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APPENDIX I

CALCULATION EQUATIONS FOR DSC_{HH}

Equations for calculating human health effects-based dust screening concentrations (DSC_{HH}) were adapted from approaches identified by CCME (2006) and WTCWG (2003).

Equations to calculate DSC_{HH} are identified for a residential scenario, a commercial scenario (where people of all ages may be present) and a constrained use commercial scenario (where only adults are expected to spend appreciable amounts of time).

Effects-Based Dust Concentrations—Surface Area Concentrations, Non-Carcinogens

For non-carcinogens, DSC_{HH} expressed on a mass per surface area basis can be calculated as follows:

(Eq.1)
$$DSC_{HH} = \frac{THQ \times TDI \times BW}{[(SA_{fingers} \times FQ \times SE \times RAF_{oral} \times EFF) + (TC \times RAF_{derm} \times EFB)] \times EF}$$

Where:

DSC_{HH}	=	human health effects-based dust screening concentrations (µg/m^2)
THQ	=	target hazard quotient (unitless)
TDI	=	tolerable daily intake (µg/kg-d)
BW	=	body weight (kg)
$SA_{fingers}$	=	surface area of fingers inserted into mouth (m^2; from Eq. 2)
FQ	=	frequency of hand-to-mouth events (hr^{-1})
SE	=	saliva extraction factor (unitless)
RAF_{oral}	=	relative oral absorption factor (unitless)
EFF	=	exposure factor for transfer to fingertips (hr/d; from Eq. 3)
TC	=	transfer coefficient (m^2/hr). The TC represents the rate of skin contact with the surface.
RAF_{derm}	=	relative dermal absorption factor (unitless)
EFB	=	exposure factor for transfer to body (hr/d; from Eq. 4)
EF	=	exposure frequency (unitless)

The most sensitive receptors for surface area DSC_{HH} for non-carcinogens are toddler (residential), toddler (commercial) and adult (constrained use commercial).

To calculate the surface area of fingers inserted into mouth:

(Eq.2)
$$SA_{fingers} = \frac{SA_{hands}}{2} \times FSA_{fingers}$$

Where:

$SA_{fingers}$	=	surface area of fingers inserted into mouth (m^2)
SA_{hands}	=	surface area of hands exposed to dust (both hands; m^2)
$FSA_{fingers}$	=	fractional surface area of fingers for mouthing activity (unitless)

To calculate the exposure factor for transfer to finger tips:

$$EFF = (HPD - TO - ST) \times (0.5 \times FTSS_{HSH} + 0.5 \times FTSS_{SSH}) \quad \text{(Eq.3)}$$

Where:

EFF	=	exposure factor for transfer to fingertips (hr/d)
HPD	=	hours spent in environment each day (hr/d)
TO	=	time spent outdoors (hr/d)
ST	=	sleep time (hr/d)
$FTSS_{HSH}$	=	fraction of dust transferred from hard surfaces to hands (unitless)
$FTSS_{SSH}$	=	fraction of dust transferred from soft surfaces to hands (unitless)

To calculate the exposure factor for transfer to the body:

$$EFB = (HPD - TO - ST) \times (0.5 \times FTSS_{HSB} + 0.5 \times FTSS_{SSB}) \quad \text{(Eq.4)}$$

Where:

EFB	=	exposure factor for transfer to body (hr/d)
HPD	=	hours spent in environment each day (hr/d)
TO	=	time spent outdoors (hr/d)
ST	=	sleep time (hr/d)
$FTSS_{HSB}$	=	fraction of dust transferred from hard surfaces to body (unitless)
$FTSS_{SSB}$	=	fraction of dust transferred from soft surfaces to body (unitless)

Effects-Based Dust Concentrations—Surface Area Concentrations, Carcinogens

For carcinogens, DSC_{HH} expressed on a mass per surface area basis can be calculated as follows:

$$DSC_{HH} = \frac{TILCR \times BW}{[(SA_{fingers} \times FQ \times SE \times RAF_{oral} \times EFF) + (TC \times RAF_{derm} \times EFB)] \times EF \times CSF} \quad \text{(Eq.5)}$$

Where:

DSC_{HH}	=	human health effects-based dust screening concentration ($\mu g/m^2$)
TILCR	=	target incremental lifetime cancer risk (unitless)
BW	=	body weight (kg)
$SA_{fingers}$	=	surface area of fingers inserted into mouth (m^2; from Eq. 2)
FQ	=	frequency of hand-to-mouth events (hr^{-1})
SE	=	saliva extraction factor (unitless)
RAF_{oral}	=	relative oral absorption factor (unitless)
EFF	=	exposure factor for transfer to fingertips (hr/d; from Eq. 3)
TC	=	transfer coefficient (m^2/hr). The TC represents the rate of skin contact with the surface.
RAF_{derm}	=	relative dermal absorption factor (unitless)
EFB	=	exposure factor for transfer to body (hr/d; from Eq. 4)
EF	=	exposure frequency (unitless)
CSF	=	cancer slope factor ($[\mu g/kg\text{-}d]^{-1}$)

Effects-Based Dust Concentrations—Bulk Dust Concentrations, Non-Carcinogens

For non-carcinogens, DSC_{HH} expressed on a mass per mass (bulk dust) basis can be calculated as follows:

(Eq.6)
$$DSC_{HH} = \frac{THQ \times TDI \times BW}{(DIG \times RAF_{oral} + [(SAF_{hands} \times SA_{hands}) + (SAF_{other} \times SA_{other})] \times RAF_{derm}) \times EF}$$

Where:

DSC_{HH}	=	human health effects-based dust screening concentration (µg/g)
THQ	=	target hazard quotient (unitless)
TDI	=	tolerable daily intake (µg/kg-d)
BW	=	body weight (kg)
DIG	=	dust ingestion rate (g/d; see Eq.8)
RAF_{oral}	=	relative oral absorption factor (unitless)
SAF_{hands}	=	skin adherence factor for dust on hands (g/m^2-d)
SA_{hands}	=	surface area of hands exposed to dust (both hands; m^2)
SAF_{other}	=	skin adherence factor for dust on other body parts (g/m^2-d)
SA_{other}	=	surface area of other body parts exposed to dust (m^2)
RAF_{derm}	=	relative dermal absorption factor (unitless)
EF	=	exposure frequency (unitless)

The most sensitive receptors for bulk dust DSC_{HH} for non-carcinogens are toddler (residential), toddler (commercial) and adult (constrained use commercial).

(Eq.7)
$$DIG = \frac{(DSL_{hard} \times \frac{SA_{hands}}{2} \times FSA_{fingers} \times FTSS_{HSH} \times FQ \times SE \times ET_{hard})}{1000} + \frac{(DSL_{soft} \times \frac{SA_{hands}}{2} \times FSA_{fingers} \times FTSS_{SSH} \times FQ \times SE \times ET_{soft})}{1000}$$

Where:

DIG	=	dust ingestion rate (g/d) (see Eq. 8)
DSL_{hard}	=	dust surface loading on horizontal hard surfaces (mg/cm^2)
SA_{hands}	=	surface area of hands exposed to dust (both hands; cm^2)
$FSA_{fingers}$	=	fractional surface area of fingers for mouthing activity (unitless)
$FTSS_{HSH}$	=	fraction of dust transferred from hard surfaces to hands (unitless)
FQ	=	frequency of hand-to-mouth events (hr^{-1})
SE	=	saliva extraction factor (unitless)
ET_{hard}	=	exposure time for contact with horizontal hard surfaces (hr/d; see Eq. 8)
DSL_{soft}	=	dust surface loading on horizontal soft surfaces (mg/cm^2)
$FTSS_{SSH}$	=	fraction of dust transferred from soft surfaces to hands (unitless)
ET_{soft}	=	exposure time for contact with horizontal soft surfaces (hr/d; see Eq. 9)
1000	=	conversion factor for mg/d to g/d

To calculate exposure time for contact with horizontal hard surfaces:

(Eq.8)[1,2]

$$ET_{hard} = (HPD - TO - ST) \times 0.5$$

Where:

ET_{hard}	=	exposure time for contact with horizontal hard surfaces (hr/d)
HPD	=	hours spent in environment each day (hr/d)
TO	=	time spent outdoors (hr/d)
ST	=	sleep time (hr/d)
0.5	=	factor to account for 50% of time exposed to hard surfaces and 50% of time exposed to soft surfaces (McDonald *et al.*, 2011)

To calculate exposure time for contact with horizontal soft surfaces:

(Eq.9)[2,3]

$$ET_{soft} = (HPD - TO - ST) \times 0.5$$

Where:

ET_{soft}	=	exposure time for contact with horizontal soft surfaces (hr/d)
HPD	=	hours spent in environment each day (hr/d)
TO	=	time spent outdoors (hr/d)
ST	=	sleep time (hr/d)
0.5	=	factor to account for 50% of time exposed to hard surfaces and 50% of time exposed to soft surfaces (McDonald *et al.*, 2011)

[1] Equation 8 is not relevant to infants

[2] In equations 8 and 9, the variables TO and ST are not applicable to a commercial scenario.

[3] Multiplication by 0.5 is not required for the infant age group (i.e., all time spent by the infant is assumed to be with soft surfaces)

Effects-Based Dust Concentrations—Bulk Dust Concentrations, Carcinogens

For carcinogens, DSC_{HH} expressed on a mass per mass bulk dust basis can be calculated as follows:

(Eq. 10)

$$DSC_{HH} = \frac{TILCR \times BW}{(DIG \times RAF_{oral} + [(SAF_{hands} \times SA_{hands}) + (SAF_{other} \times SA_{other})] \times RAF_{derm}) \times EF \times CSF}$$

Where:

DSC_{HH}	=	human health effects-based dust screening concentration (µg/g)
TILCR	=	target incremental lifetime cancer risk (unitless)
BW	=	body weight (kg)
DIG	=	dust ingestion rate (g/d; see Eq. 8)
RAF_{oral}	=	relative oral absorption factor (unitless)
SAF_{hands}	=	skin adherence factor for dust on hands (g/m^2-d)
SA_{hands}	=	surface area of hands exposed to dust (both hands; m^2)
SAF_{other}	=	skin adherence factor for dust on other body parts (g/m^2-d)
SA_{other}	=	surface area of other body parts exposed to dust (m^2)
RAF_{derm}	=	relative dermal absorption factor (unitless)
EF	=	exposure frequency (unitless)
CSF	=	cancer slope factor $([\mu g/kg\text{-}d]^{-1})$

APPENDIX II

EQUATIONS FOR EXPOSURE ASSESSMENT OF DUST IN HHRAs

Within an HHRA, the equations used to estimate exposure to COPCs in dust are slightly different from those used to calculate DSC_{HH} which can be used to screen COPCs in dust. Equations are presented below for assessment of exposure to indoor dust in an HHRA. These exposure calculations would then be integrated with a multi-media exposure assessment.

Estimation of Oral Exposure on an Area-Weighted Basis

(Eq.1)

$$EID_{total} = \frac{DCA_{hard} \times ET_{hard} \times FTSS_{HSH} \times SA_{fingers} \times FQ \times SE \times RAF_{oral} \times EF}{BW} + \frac{DCA_{soft} \times ET_{soft} \times FTSS_{SSH} \times SA_{fingers} \times FQ \times SE \times RAF_{oral} \times EF}{BW}$$

Where:

EID_{total}	=	exposure from dust ingestion from hard and soft surfaces (µg/kg-d)
DCA_{hard}	=	dust concentration from hard surfaces on an area-weighted basis (µg/m^2)
ET_{hard}	=	exposure time for contact with horizontal hard surfaces (hr/d; from Eq. 2)
$FTSS_{HSH}$	=	fraction of dust transferred from hard surfaces to hands (unitless)
$SA_{fingers}$	=	surface area of fingers inserted into mouth (m^2; from Eq. 3)
FQ	=	frequency of hand-to-mouth events (hr^{-1})
SE	=	saliva extraction factor (unitless)
RAF_{oral}	=	relative oral absorption factor (unitless)
EF	=	exposure frequency (unitless)
BW	=	body weight (kg)
DCA_{soft}	=	dust concentration from soft surfaces on an area-weighted basis (µg/m^2)
ET_{soft}	=	exposure time for contact with horizontal soft surfaces (hr/d; from Eq. 4)
$FTSS_{SSH}$	=	fraction of dust transferred from soft surfaces to hands (unitless)

To calculate exposure time for contact with horizontal hard surfaces:

(Eq.2)

$$ET_{hard} = (HPD - TO - ST) \times 0.5$$

Where:

ET_{hard}	=	exposure time for contact with horizontal hard surfaces (hr/d)
HPD	=	hours spent in environment each day (hr/d)
TO	=	time spent outdoors (hr/d)
ST	=	sleep time (hr/d)
0.5	=	factor to account for 50% of time exposed to hard surfaces and 50% of time exposed to soft surfaces (McDonald *et al.*, 2011).

To calculate the surface area of fingers inserted into mouth:

(Eq.3)

$$SA_{fingers} = \frac{SA_{hands}}{2} \times FSA_{fingers}$$

Where:

$SA_{fingers}$ = surface area of fingers inserted into mouth (m^2)
SA_{hands} = surface area of hands exposed to dust (both hands; m^2)
$FSA_{fingers}$ = fractional surface area of fingers for mouthing activity (unitless)

To calculate exposure time for contact with horizontal soft surfaces:

(Eq.4)

$$ET_{soft} = (HPD - TO - ST) \times 0.5$$

Where:

ET_{soft} = exposure time for contact with horizontal soft surfaces (hr/d)
HPD = hours spent in environment each day (hr/d)
TO = time spent outdoors (hr/d)
ST = sleep time (hr/d)
0.5 = factor to account for 50% of time exposed to hard surfaces and 50% of time exposed to soft surfaces (McDonald *et al.*, 2011).

Estimation of Dermal Exposure on an Area-Weighted Basis

(Eq.5)

$$EDD_{total} = \frac{DCA_{hard} \times TC \times ET_{hard} \times FTSS_{HSH} \times RAF_{dermal} \times EF}{BW} + \frac{DCA_{hard} \times TC \times ET_{soft} \times FTSS_{SSH} \times RAF_{dermal} \times EF}{BW}$$

Where:

EDD_{total} = exposure from dermal contact with indoor dust from hard and soft surfaces (µg/kg-d)
DCA_{hard} = dust concentration from hard surfaces on an area-weighted basis (µg/m^2)
TC = transfer coefficient (m^2/hr)
ET_{hard} = exposure time for contact with horizontal hard surfaces (hr/d; from Eq. 2)
$FTSS_{HSH}$ = fraction of dust transferred from hard surfaces to hands (unitless)
RAF_{dermal} = relative dermal absorption factor (unitless)
EF = exposure frequency (unitless)
BW = body weight (kg)
DCA_{soft} = dust concentration from soft surfaces on an area-weighted basis (µg/m^2)
ET_{soft} = exposure time for contact with horizontal soft surfaces (hr/d; from Eq. 4)
$FTSS_{SSH}$ = fraction of dust transferred from soft surfaces to hands (unitless)

Estimation of Total Exposure on an Area-Weighted Basis

(Eq.6)

$$EAD_{total} = EID_{total} + EDD_{total}$$

Where:

EAD_{total} = exposure to dust from ingestion and dermal pathways (µg/kg-d)
EID_{total} = exposure from dust ingestion from hard and soft surfaces (µg/kg-d)
EDD_{total} = exposure from dermal contact with indoor dust from hard and soft surfaces (µg/kg-d)

Estimation of Oral Exposure from Bulk Dust Concentrations

(Eq.7)

$$EID = \frac{BDC \times DIG \times RAF_{oral} \times EF}{BW}$$

Where:

EID = exposure from dust ingestion from horizontal surfaces (µg/kg-d)
BDC = bulk dust concentration on horizontal surfaces (µg/g)
DIG = dust ingestion rate (g/d; see Eq. 8)
RAF_{oral} = relative oral absorption factor (unitless)
EF = exposure frequency (unitless)
BW = body weight (kg)

To calculate the dust ingestion rate:

(Eq.8)

$$DIG = \frac{(DSL_{hard} \times \frac{SA_{hands}}{2} \times FSA_{fingers} \times FTSS_{HSH} \times FQ \times SE \times ET_{hard})}{1000} + \frac{(DSL_{soft} \times \frac{SA_{hands}}{2} \times FSA_{fingers} \times FTSS_{SSH} \times FQ \times SE \times ET_{soft})}{1000}$$

Where:

DIG = dust ingestion rate (g/d)
DSL_{hard} = dust surface loading on horizontal hard surfaces (mg/cm^2)
SA_{hands} = surface area of hands exposed to dust (both hands; cm^2)
$FSA_{fingers}$ = fractional surface area of fingers for mouthing activity (unitless)
$FTSS_{HSH}$ = fraction of dust transferred from hard surfaces to hands (unitless)
FQ = frequency of hand-to-mouth events (hr^{-1})
SE = saliva extraction factor (unitless)
ET_{hard} = exposure time for contact with horizontal hard surfaces (hr/d; see Eq. 2)
DSL_{soft} = dust surface loading on horizontal soft surfaces (mg/cm^2)
$FTSS_{SSH}$ = fraction of dust transferred from soft surfaces to hands (unitless)
ET_{soft} = exposure time for contact with horizontal soft surfaces (hr/d; see Eq. 4)
1000 = conversion factor for mg/d to g/d

Estimation of Dermal Exposure from Bulk Dust Concentrations

(Eq.9)

$$EDD = \frac{BDC \times ([SAF_{hands} \times SA_{hands}] + [SAF_{other} \times SA_{other}]) \times RAF_{dermal} \times EF}{BW}$$

Where:

EDD	=	exposure from dermal contact with indoor dust from horizontal surfaces (µg/kg-d)
BDC	=	bulk dust concentration on horizontal surfaces (µg/g)
SAF_{hands}	=	skin adherence factor for dust on hands (g/m^2-d)
SA_{hands}	=	surface area of hands exposed to dust (both hands; m^2)
SAF_{other}	=	skin adherence factor for dust on other body parts (g/m^2-d)
SA_{other}	=	surface area of other body parts exposed to dust (m^2)
RAF_{dermal}	=	relative dermal absorption factor (unitless)
EF	=	exposure frequency (unitless)
BW	=	body weight (kg)

Estimation of Total Exposure from Bulk Dust Concentrations

(Eq.10)

$$EAD_{total} = EID_{total} + EDD_{total}$$

Where:

EAD_{total}	=	exposure to dust from ingestion and dermal pathways (µg/kg-d)
EID_{total}	=	exposure from dust ingestion from horizontal surfaces (µg/kg-d)
EDD_{total}	=	exposure from dermal contact with indoor dust from horizontal surfaces (µg/kg-d)